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FIBRE REINFORCED PLASTICS INDUSTRIAL COMPOSITES

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CONTENT

Abstract

The following presentation will briefly describe selected composite materials, with emphasis on industrial technologies available for the production of polymeric composites, which are different from those for production of advanced polymeric composites.
Continuous production processes, such as pultrusion, and related applications will be addressed. Finally attention will be devoted in to recent developments regarding research, technological innovation, and applications of fibre-reinforced plastics for renovation, rehabilitation, and strengthening of reinforced concrete and of masonry structures.

I. INTRODUCTION TO COMPOSITES

A. Introduction And Definitions

structural applic
consisting of two phases: one continuous phase (matrix) and one non-continuous phase (reinforcement) oriented according to requirements.
The matrix has the function to hold firmly together the fibrous reinforcements. From this derives the more

Composites may be of 3 types: plastic, metallic, or ceramic, depending on the type of matrix and on the type of reinforcement (metal fibres, glass fibres, ceramic fibres).
There is also a distinction between short fibre and continuous fibre- composites, depending on the nature of the reinforcement.

In this presentation we will refer exclusively to plastic composites, in other words, composites made of polymeric matrix and fibre-reinforcements (FRP = Fibre Reinforced Plastics).
These materials, originally developed for aeronautical and mechanical applications, later have been used for several other applications in civil engineering, such as reinforcements for regular and for pre-stressed concrete structures; also, many products have been developed specifically for rehabilitation and strengthening of structures.
The elevated mechanical resistance, the excellent resistance to corrosion and weathering, the ease of handling and installation due to the light weight, have all contributed to develop very important applications all over the World.
The increasing utilization of these materials is demanding a lot of activity for standardization (ACI in USA, JSCE in Japan, and CAN in Canada).
In Europe the CEB committee is also working on recommendations.

II. THE MATERIALS

Let us now look at the components of FRP: Fibres and Matrices.

A. Fibres

The most utilised reinforcing fibres are:

- Glass fibres;
- Carbon fibres;
- Aramidic fibers.

In the following table we are showing some typical mechanical properties (average, approximate, values).

Fiber Type	Elastic Modulus (Mpa)	Tensile Strength (Mpa)	Density (gr/cc)
Glass fibres	70.000	3.000	2,5
High modulus carbon fibres	400.000	2.400	1,9
High resistance carbon	240.000	4.800	1,8
High modulus aramidic fibres	140.000	2.200	1,5
High yeld aramidic fibres	60.000	3.100	1,5

Glass fibers are the most utilised, because they offer a good compromise between cost and mechanical properties.

B. MATRIX

The most utilised matrices for plastic composites are of two types: thermoset resins and thermoplastic resins:

- The thermoset resins are usually in the form of medium viscosity liquid, actually monomers often dissolved in solvents, which, after wetting the reinforced fibres polymerise in the presence of catalyst and heat. The solidification of the resin (polymerisation) is irreversible: that means, if the solid product is heated, it will never return to the fluid state; moreover, if the temperature becomes very high, the solid will degrade and eventually burn. For this reason it is not possible to perform on these products any post-working operations, such as thermoforming, bending, welding, etc.
  Almost all resins utilised for composites in concrete reinforcement are thermoset.

- Thermoplastic resins are usually in the form of granules or powders. Heat and sometimes solvents are needed to fluidise the polymers so that they can impregnate the reinforcement or be moulded. In such case the change of phase from solid to fluid is reversible and post-operations where you need to soften the product are possible.

For civil engineering applications, mostly thermoset polyester or epoxy resins are utilised.
Polymerisation of polyester starts when heating and pressure are applied.
Total hardening (curing) is reached when there are no monomers left either in the polyester or in the solvent; they all become part of the structure of the polymerised polyester.

Polyester resins can be identified in the following cost-increasing order:
- Orthoftalic,
- Isophtalic,
- Vinylester.

The following table shows typical characteristics of a polyester resin.

Elastic Modulus	4500 Mpa
Bending Strength	100 Mpa
Elongation at break	2%
Water absorption	0,2 %
Specific Weight	1,2 gr/cc

Properties of the resins and consequently of the finished product can be greatly varied by adding fillers, polymers, etc.

Epoxy resins

There are thermoset, as well as thermoplastic epoxies.

There are two main families of epoxy resins: the epoxy resins based on Bisphenol-A and those based on Novalac resin: one for manufacts for electric applications, the other for out-door applications. There is also a large number of minor epoxies, each offering different characteristics.

The viscosity of an epoxy may vary from medium to very large values. Often the viscosity must be adjusted for a given process by adding a quantity of proper solvent.

The curing (polymerisation) of an epoxy resin, be it a thermoset or a thermoplastic, can be obtained by reacting the resin with a specific hardener (many type of curing agents are available, each also affecting properties of the final product). Curing can be performed at room temperature or at elevated temperatures without emission of volatiles.

Following is a table showing characteristics of a typical epoxy resin utilised for production of composites:

Elastic Modulus	4.500 Mpa
Bending Strength	100 Mpa
Elongation at break	2-5%
Water absorption	0,05 0,3 %
Specific Weight	1,3 2,5 gr/cc

It is also possible to affect characteristics of the finished product by utilising fillers and/or other additives.

III. PROPERTIES OF THE MANUFACTS

Mechanical, physical and electric properties are dependant on the nature and the volume components materials, as well as on the production technique.

For example, a rod manufactured with 60% by volume of glass unidirectional reinforcement with e-modulus 70 Gpa, impregnated with a polyester resin 4.5 GP modulus, will typically show an elastic modulus = 0.6 x 70 + 0.4 x 4.5 = 43.8 GP

MANUFACTURING OF FIBER REINFORCED COMPOSITES

ADVANCED COMPOSITES — HIGH PERFORMANCE

- Autoclave lamination
- Filament Winding

INDUSTRIAL COMPOSITES — LOW PERFORMANCE

- Pultrusion
- Resin transfer moulding
- Vacuum bagging and liquid infusion processes
- Compression moulding
- Hand lay-up and spray-up
- SMC and BMC

As you can see from the above table, autoclave lamination and pre-peg filament winding are the techniques utilised for production of advanced composites. The anhisothropy of the materials is utilised to maximise performance in the wanted direction therefore taking maximum advantage of the materials potentiality. Advanced composites find applications for aircraft and aerospace components, as well as sports and recreation. For these applications the technical performance takes priority over economics.

Industrial composites are produced by pultrusion, non-sophisticated filament winding, resin transfer moulding, etc. as listed in the preceding table. Successful marketing of industrial composites depends on a good combination of economics and technical performance. The following table illustrates some industrial applications:

Production Technology	**Products Components**	**Markets / Applications**
Pultrusion	- Ladder components - Cable trays - Structural shapes - Light Poles - Grating - Window frames - Roof supports - Standard structures	- Electric - Corrosion and marine - Industrial - Construction - Transportation
Filament Winding	- Pipes and tanks	- Chemical industry - Foodstuff industry - Infra-structures
Compression moulding and RTM	- More or less complex manufatcs	- Transportation
SMB / BMC	- Electric cabinets - Automobile bumpers - Auto parts - Computer and electronic components	- Electric - Automotive -Appliances
Hand lay-up	-Agricultural small tanks and containers - Custom parts	- Agriculture - Corrosion resistance

We would like now to illustrate the pultrusion technology.

It is well known that composites have failed to develop the expected large volumes in sales.
This is due to the fact that mass production industrial techniques have not been developed.
As a matter of fact, while composites offer an enormous potential in terms of performance, as compared to traditional materials, it is also true that the high production costs have greatly penalised their popularity.

Pultrusion is the only industrial technology that allows, for manufacts with limited types of loads, to yield products with high performance at relatively low cost. Let us show you why:

Pultrusion represents the only technology for continuous production of constant section shapes, even very complex, with very good mechanical properties.
The sketch shows a simplified picture of a pultrusion line.
The process consists in continuously pulling fibres impregnated with thermoset resins through a heated metallic high precision die.
The heat applied to the die starts the polymerisation reaction and the speed of production is such that at the exit of the die the finished hard product comes out.
At the end of the line, a saw is placed to cut the profile at the desired length. Length of the product is only limited by transportation means.
If necessary, post-working equipment can be placed in the line to bore holes, machine threads, or other.
The most utilized reinforcements for pultrusion are Glass continuous fibres and Carbon Continuous Fibres; much less utilized are the Aramidic.
The most common matrices are based on thermo set polyester, vinyl-ester, epoxy resins; occasionally acrylic and phenolic resins are used.

By looking at the production technology, which in poor words consists in pulling impregnated fibers through a heated die, it is easy to understand why we can expect the best performance to be in the direction of the axis of the product. As a matter of fact, for structural applications, pultruded structural shapes are almost exclusively utilized where pull strength or bending strength are the characteristics required.

Within these applications I would like to show particularly some consolidations products for which ATP is today leader world-wide

IV. CFRP PRODUCTS

In the last decade, also thanks to the reduction of costs of carbon fibres, we have experienced a very interesting growth for the utilization of Carbon Pultruded Composites in the form of rods of several diameters and of plates of several thickness and width as structural reinforcement in civil engineering.

Usually it becomes necessary to intervene on a structure when:

- There is damage to the structure caused by external events, such as: earthquakes, fires, explosions, etc.)
- Damage to the structure is caused by very aggressive environment, such as marine salt water, high humidity and temperature, etc.
- The load for which the structure was designed is exceeded for any reason, such as change of type of utilization increased traffic loads, design errors.

Rehabilitation and extraordinary maintenance of monuments, historical buildings and civil engineering structures represent huge phenomena in Italy and particularly in our area, the Regione Campania, which is heavily involved in recuperating the vast historical heritage. In this area the historical sites and structures, as

well as residential centres, have suffered, from aging, and from overloads by ever increasing road transportation. Some Example of Applications CFRP Products:

1. Damaged beam reinforcement
2. Weakened wall reinforcement

R&D in the past couple of years or so has been more anymore involved exclusively with development of CFRP products for the restauration and rehabilitation applications. This activity includes:

- Design & Prototyping of new shapes, forms & systems
- Self monitoring materials
- Analytical models
- Joining and bonding techniques
- Long term performance
- Full scale Lab and Job-site testing, including Design of testing procedures and testing equipment.
- Production Optimisation
- Design and application of Quality Control Procedures
- Design guidelines, specs, standards.

A lot of this activity is going on the area of Regione Campania.
ATP is also involved in some of this activity.

V. CONCLUSIONS

- The high cost of production has hampered marketing of advanced composites for structural applications, with the exception of some special areas such as aeronautics, aerospace, sports, and recreations where the technical aspect overrides the economical one.
- There are quite a few valuable opportunities for applications of pultruded manufacts in civil engineering; this success is due to the fact that pultrusion is the only continuous, automatic, industrial process for mass production of fairly high quality composites, which essentially means low production costs.